US Army Corps of Engineers®
Cold Regions Research & Engineering Laboratory

Ice Engineering

U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

Performance Survey of Inflatable Dams in Ice-Affected Waters

Since their first appearance in the mid 1950s, inflatable dams have gained increasing acceptance. There are now more than 2000 of these structures in use worldwide,[1] with an increasing proportion in ice-affected waters. The purpose of this survey is to document the performance of existing inflatable dams in rivers with ice, and outline potential expanded uses in the field of river ice control.

Inflatable dam applications include headgates for irrigation, water supply and hydropower, flashboard replacement, raising the crest of an existing dam or reservoir spillway, tidal barriers, sewage treatment lagoons, sediment discharge gates, and groundwater recharging. Although inflatable dams have many advantages in ice-affected waters, none have been built for the specific purpose of ice control.

An inflatable dam consists of an air-filled tube clamped to a concrete sill (Fig. 1). The tube is made of a laminated rubber and nylon material that ranges in thickness from 10 to 25 mm, depending on the height of the dam. Inflatable dams range in height from about 0.4 to 4.6 m (1.3 to 15 ft) and the individual span lengths range from about 6 to 89 m (20 to 290 ft). The structures are best suited to situations where the width-to-length ratio is relatively high, typically greater than five.

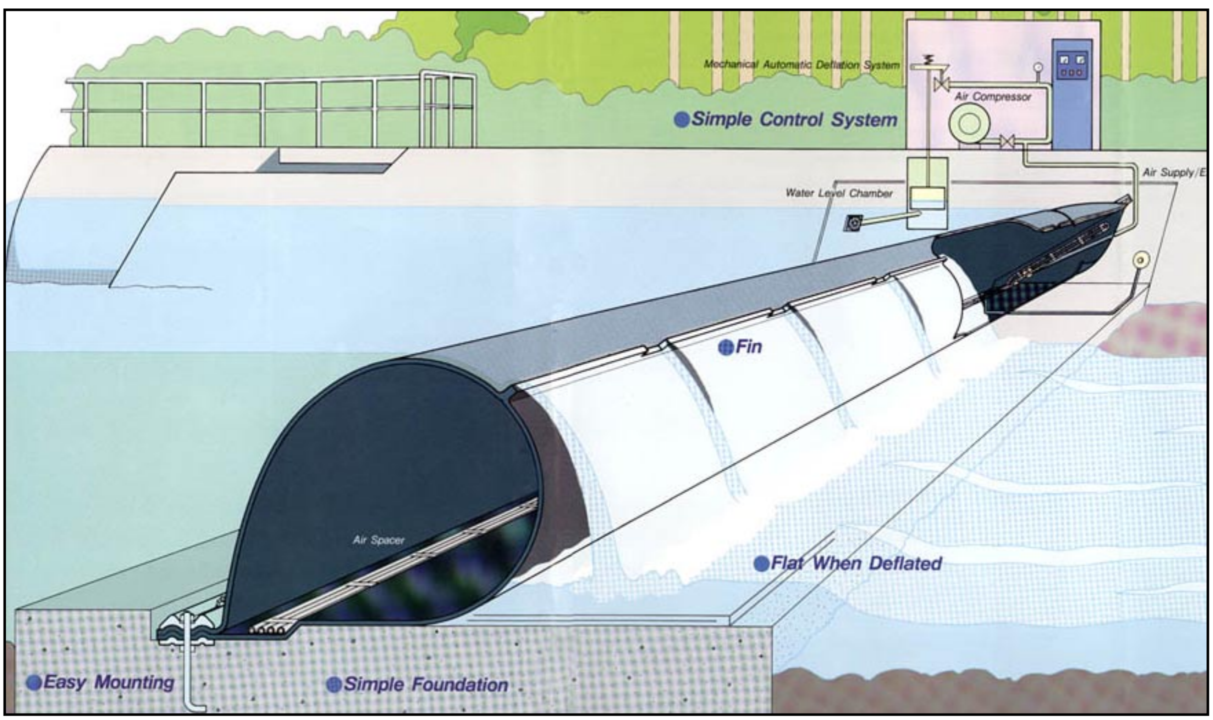

Figure 1. Cross section of an inflatable dam.
(Diagram courtesy of www.bridgestoneindustrial.com/RubberDam/design.htm.)

[1] Personal communication, Roger Campbell, Bridgestone Industrial Products America, Inc., New York, 18 October 1999.

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
00 Oct 2001	N/A	-

Title and Subtitle Performance Survey of Inflatable Dams in Ice-Affected Waters	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) USACE Engineer Research and Development Center Cold Regions Research and Engineering Laborator 72 Lyme Road Hanover, New Hampshire 03755-1290	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es)	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes The original document contains color images.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 6	

The dams are inflated by high-volume, low-pressure compressors called "blowers" and are emptied through exhaust valves. The dam can be deflated to pass flood flows, to drain the pool, or to bypass flow during turbine shutdowns. An automatic control system operates the blowers and exhaust valves to maintain a set pool elevation or a set air pressure inside the dam. The blowers and exhaust valves also can be operated manually. When fully deflated, the rubber tube lies flat on the concrete foundation. Internal air pressure is low, varying from about 7 to 55 KPa gage (1 to 8 psi), depending on dam height. Side bulkheads and intermediate piers can be either vertical or sloping to conform to the natural side slope of the river.

The first inflatable dam, an Imbertson Fabridam composed of rubberized canvas, was built in California in 1956 and was manufactured by Firestone. Some of these early structures were inflated by water rather than air. Because they did not lie completely flat when deflated, the dams would oscillate with the river current and abrade against the concrete sill, eventually developing holes. In the 1970s, Bridgestone developed an air-inflated dam made of a tougher ethylene propylene diene monomer (EPDM) rubber compound. The dam laid flat on the foundation when deflated, avoiding abrasion. A fin on the downstream side of the dam provided nappe separation, preventing oscillation-induced vibration of the dam when inflated.

Advantages of inflatable dams

Advantages of inflatable over conventional concrete dams with metal gates include a lower initial cost and lower maintenance costs due to the lack of gate mechanisms and the need to paint. Because the sills for inflatable dams can be constructed to conform to the existing channel, the dam's environmental impact when deflated is minimal. Depending on sill geometry and water level, fish passage may be possible over the deflated dam. This low profile also allows passage of flood flows with a minimal increase in upstream stage. If the concrete sill is low enough, bed load and suspended sediment can also pass over the deflated dam, reducing deposition and loss of storage capacity in the upstream impoundment. Finally, the capability for wide pier spacing and absence of a superstructure optimizes debris and ice passage and improves aesthetics.

The initial cost of an inflatable dam, including its sill, blowers, and control system, is significantly lower than the equivalent steel-gated, concrete structure. As an example, in 1986, the Corps constructed a steel-gated, concrete ice control weir on Oil Creek in Pennsylvania at a total cost of $2.2 million. A similar-sized inflatable dam structure is estimated to cost about $1.5 million.[2]

An inflatable dam has no gate-lifting mechanisms to be maintained or kept from freezing in winter. With the dam fully inflated, there is no seepage through side or bottom seals, as is often the case with conventional steel gates. In the winter, this dry downstream condition eliminates icing of sideseals and the apron; in the summer, weed growth is minimized. Ice that does adhere to the inflated dam easily breaks off when the dam is deflated, even under extremely cold temperatures.

Disadvantages and concerns regarding inflatable dams

Some disadvantages of inflatable dams are a shorter design life, vulnerability to vandalism, and uncertainty due to the newness of the technology. Also, when spilling, a low area or "vee notch" tends to form, concentrating the flow in that region. A final drawback is that most types of inflatable dams are manufactured overseas, making it more difficult for federal agencies such as the Corps of Engineers to purchase the products.

The first Bridgestone inflatable dams came on the market in 1978 with an estimated design life of 30 years. However, two spans of a Bridgestone dam installed in 1986 on the Susquehanna River at Sunbury, Pennsylvania, developed air bubbles in the corners of the outer protective layers and had to be replaced in 2000, at half their estimated design life.[3] A possible reason is that the dam was completely deflated during the winter months and may have been damaged by debris and ice.

A high-powered rifle round will penetrate an inflatable dam, but at the relatively low internal pressures the resulting air loss is slow enough that the blowers can compensate until the bag is repaired. This occurred at the Broadwater Dam on the Missouri River at Townsend, Montana.[4] A Bridgestone dam at a water supply reservoir near Norwich, Connecticut, failed completely during the summer of 1999 when some youths kindled a large campfire on the downstream side of the airbag. Although the 180-hectare (450-acre) reservoir quickly lost 1.5 m (5 ft) of pool, there were no injuries or significant damage to downstream property.

[2] Estimate by Ed Foltyn, Hydraulic Engineer, USACRREL (retired), 1989.

[3] Personal communication, Mary Lorah, Manager, Shikellamy State Park, Sunbury, Pennsylvania, January 2000.

[4] Personal communication, Brian Carroll, Plant Manager, Broadwater Hydroelectric Station, Townsend, Montana, 25 January 2000.

Vee-notch formation while spilling water has potential drawbacks. The first is that concentration of flow downstream of the dam may result in scour and possible foundation damage. Also, with an uneven crest height, it is difficult to estimate the depth of flow over the dam, and the water discharge being spilled.

Table 1. Examples of inflatable dams in ice-affected waters.

Project/ location	Year built	Manufacturer/ dimensions *(m)*	Owner/ operator	Use	Comments	Points of contact
Palmer Falls Hudson River Corinth, NY	1987	Bridgestone 1.83 _ 45.5 1.83 _ 61.6	International Paper	Hydro (50 MW)	Performs well during ice season. Passes ice and debris without problems.	Tom Ucher 518-654-3440
Susquehanna River Sunbury, PA	1984–1988	Bridgestone Six 2.44 _ 88.7 One 2.44 _ 50.6	Pennsylvania State Bureau of Parks	Recreational lake	Replaced Fabridam bags. Deflated all winter. Two bags now leak and must be replaced.	Mary Lorah 570-988-5557
Broadwater Station Missouri River Townsend, MT	1988	Bridgestone Seven 3.4 _ 16.5	Montana Power	Hydro (10 MW)	Performs well during ice season. Passes ice and debris without problems. Small leaks in creases near bulkheads.	Brian Carroll 406-266-3869
Rainbow Falls Missouri River Great Falls, MT	1989	Bridgestone Two 3.5 _ 67.67	Pacific Power and Light	Hydro (35 MW)	Performs well during ice season. Passes ice and debris without problems.	Rich Halverson 406-266-3869
Bolton Falls Winooski River Bolton, VT	About 1990	Bridgestone About 1.5 _ 30	Green Mountain Power	Hydro (8.8 MW)	Withstands severe breakup ice runs without problems.	William Conn 802-864-5731
Highgate Falls, Missisquoi River, Highgate, VT	1992	Bridgestone 4.57 _ 67	Village of Swanton, VT	Hydro (9.8 MW)	Highest inflatable dam in the world. Excellent performance in ice. Eliminated freezeup and breakup ice problems at project.	Alan Mosher 802-868-4200
Silvian Station Mississippi River Brainerd, MN	1992	Bridgestone 1.3 _ 6.1	Minnesota Power	Hydro (2 MW)	Performs well in extreme cold. Solved downstream icing and weed problems.	Dave Nixon 218-722-5642
Stoney Brook Reservoir Norwich, CT	1996	Bridgestone 1.53 _ 15	City of Norwich, Department of Public Utilities	Increases spillway crest height of reservoir	Fully inflated except during floods. Failed in 1999 as a result of vandalism.	John Bilda 860-823-4192

Inflatable dam applications in ice-affected waters

The main use of inflatable dams in ice-affected waters has been for small run-of-the-river hydroelectric plants at sites in the northern United States. The inflatable dams are often installed to replace older flashboard systems, or to increase the depth of an impoundment and provide crest control. At these facilities, the dam is fully inflated most of the time while pool elevation is controlled by turbine settings.

In the event of a large runoff event or a turbine shutdown, pool elevation is regulated by changes in air pressure and the height of the dam. During spring ice breakup, it may be possible to lower the inflatable dam sufficiently to avoid a large upstream water level rise and maintain an intact sheet ice cover. Otherwise, inflatable dams perform well at passing ice and debris. Most operators agree that passing debris with sharp steel protrusions—old refrigerators, bridge planks with spikes sticking out, etc.—pose a greater threat to the dam than ice and trees.

Table 1 lists eight examples of inflatable dams in the northern United States. All but two are at hydroelectric projects. Reportedly, many small hydroelectric projects in Canada are also switching to inflatable dams for crest control or flashboard

replacement.[5] To illustrate performance in ice conditions, several of the projects listed in Table 1 are described in greater detail below.

Broadwater Dam, Missouri River, Townsend, Montana

Broadwater Station is a run-of-the-river hydro plant, with a head of 6.7 m (22 ft) and a capacity of 10 MW. Under normal flow conditions of 110–170 m^3/s (4000–6000 cfs), all discharge goes through the turbines. In 1988, the flashboards were replaced with seven 3.4-m _ 16.5-m (11-ft _ 54-ft) Bridgestone inflatable dams between vertical-sided concrete bulkheads (Fig. 2). In the event of a turbine shutdown, all flow passes over the dam. Except during high-flow periods, the air bag inflation/deflation system and turbines are operated to maintain a constant pool level year-round.

Typical winter discharge is fairly constant at about 110 m^3/s (4000 cfs), and the sheet ice on the pool can reach thicknesses in excess of 0.6 m (2 ft). Ice breakup usually occurs over a two-day period in late February, during which time the river flow usually increases 50% to around 170 m^3/s (6000 cfs). During breakup, large ice floes, trees, pieces of washed-out bridges, and telephone poles (wires and all) pass over the air bags on the dam. Long pieces of debris sometimes lodge between the concrete piers and must be dislodged using long poles, or cut in half with chainsaws. The ice-out is usually followed by a rainy season with higher open water flows. During the maximum flow experienced since installation, 1080 m^3/s (38,000 cfs), the air bags were completely deflated.

Some of the air bags leak in the crease areas near the concrete bulkheads. Also, leaks in the upstream and downstream faces of one airbag resulting from a high-powered rifle round were mended using a tubeless tire repair kit. Brian Carroll, who has been at the project since the installation of the inflatable dam, is very pleased with its performance.

Figure 2. Ice and debris passing over Broadwater Dam on the Missouri River at Townsend, Montana. Note the vee notch in the airbag near the land-side bulkhead.

[5] Personal communication, William Conn, Green Mountain Power, Burlington, Vermont, 25 January 2000.

Highgate Falls Power Dam, Swanton, Vermont

A 4.6-m-high by 67-m-long (15-ft by 220-ft) Bridgestone inflatable dam regulates pool elevation at a 9.8-MW hydroelectric plant owned by the village of Swanton, Vermont, on the Missisquoi River at Highgate Falls. Figure 3 shows the dam in its fully inflated configuration. Plant Manager Alan Mosher describes the new dam as a godsend in terms of reducing ice problems.

The 1992 construction of the Highgate Falls inflatable dam, on a 5-ft-high concrete sill, raised pond elevation by a total of 6.1 m (20 ft). It is one of the highest in existence, and it is possible to walk inside for inspection and repair purposes. When fully inflated, the inside air pressure is 52 KPa gage (7.5 psi). The dam is constructed of 18-ply rubber about 25 mm (1 in.) thick.

Figure 3. Highgate Falls Dam, fully inflated, 21 January 2000.

Although vandalism has not been a problem to date, Mosher believes that it would be difficult for anyone to cause a catastrophic failure. Bullet holes would result in slow leaks that could be easily repaired from the inside. In a test, a 30.06 steel jacket bullet went through a sample piece of the air bag material, but 22 caliber and 30.06 soft point bullets failed to penetrate. Mr. Mosher recollects that the cost of the inflatable dam and associated equipment was about $1.2 million.

The higher pool allowed the area of the hydroelectric intakes area to be doubled, reducing water velocity near the trash racks. The frazil ice blockage problems that existed before the raising of the pool were solved, and debris collection problems minimized. Breakup ice runs passed over the old dam, often destroying the wooden flashboards. Setting and maintaining the flashboards was time-consuming and, to some extent, risky. With the inflatable dam, flashboards are no longer necessary. Before the inflatable dam was installed, breakup ice runs were a problem. In addition to damaging the flashboards the hydroelectric plant downstream of the dam was inundated in 1979 as the result of a breakup ice jam. In March 1992 a severe breakup ice run damaged the structural steel in the footings to the new dam while under construction. With the inflatable dam, it is possible to minimize stage rise in the head pond during breakup by progressively lowering the crest height of the dam as river flow increases. This practice helps preserve the intact sheet ice cover, often allowing it to melt in place rather than break up and move downstream as in the past. Mosher has witnessed ice blocks as thick as 1.2 m (4 ft) passing over the dam crest. He said that at times large ice pieces or floes will hang up on the dam, requiring a temporary lowering of the crest height to get the ice moving again.

Silvian Hydro Station, Minnesota Power, Mississippi River near Brainerd, Minnesota

A 1.3-m _ 6.1-m (4.3-ft _ 20-ft) Bridgestone inflatable dam was installed about nine years ago at this 2-MW run-of-the-river hydro project. Operators are very happy with the new dam's performance to date. The inflatable dam solved the constant leakage of the previous flashboard system, eliminating icing problems in the winter and weed buildup in summer. The concrete apron is now completely dry when the dam is up. The dam is fully inflated except for when the turbines go offline. The dam has been lowered in the dead of winter as a test, and the rubber surface easily broke free of the 1.2-m- (4-ft-) thick ice cover on the pool.

Although the dam's width-to-height ratio is five, which is near the maximum for an inflatable dam, it has worked well to date. There have been no leakage problems at the edges (perhaps because the bag is not deflated that often). The dam's cost,

including some rehabilitation to the concrete piers, was $60,000. Minnesota Power would like to replace flashboards with inflatable dams at many more of its sites, but is forced to move slowly because of the cost. Dave Nixon in engineering mentioned that Obermeyer gate systems, which use air bladders to lift hinged steel gates, are also being considered. The Obermeyer gates fit into narrower bays, but have the side leakage and icing problems of conventional mechanical gates.

Conclusions

Based on survey results, inflatable dams perform well in ice-affected rivers and they have a number of advantages over conventional, mechanically operated gates. To date, the primary use of inflatable dams in the northern United States and Canada has been for flashboard replacement and crest control at small hydroelectric projects. In addition to the advantages of lower initial cost and minimal moving parts, inflatable dams appear to be well adapted to winter operations. Ice adhesion, seal leakage and freezing, as well as ice and debris passage, have not been problems.

Inflatable dams can be operated to maintain a constant pool level, delaying or preventing breakup of the upstream ice cover and protecting downstream locations from ice jam flooding. On steeper streams and rivers, low-profile inflatable dams would be ideal for creating shallow pools or series of pools to speed ice cover formation and reduce frazil production and subsequent freezeup or breakup ice jam flooding. The airbags would rest deflated on the riverbed when unneeded, allowing fish migration and natural movement of sediment.

Finally, inflatable dams might provide an attractive option in the recent trend towards removal of dams to return rivers to their natural condition. In most cases, the lowering or removal of a dam changes the ice regime on a river with possibly negative effects. For example, frazil ice that once collected behind the dam might move downstream to form a freezeup ice jam and flooding at an undesirable location. As insurance against unforeseen ice problems associated with the dam removal or lowering, the project could incorporate the construction of a sill to accept an inflatable dam if needed.

Acknowledgments

This work was funded by Work Unit 33137, *Ice Mitigation for Navigable Rivers*, Cold Regions Engineering Program.

*   *   *

This issue of Ice Engineering *was written by Andrew M. Tuthill, Research Hydraulic Engineer, Ice Engineering Group, RS/GIS/Water Resources Branch, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Engineer Research and Development Center (ERDC), Hanover, New Hampshire.*

Ice Engineering Information Exchange Bulletin

The *Ice Engineering Information Exchange Bulletin* is published in accordance with AR 25-30 as one of the information exchange functions of the Corps of Engineers. It is primarily intended to be a forum whereby information on ice engineering work done or managed by Corps field offices can be disseminated to other Corps offices, other U.S. Government agencies, and the engineering community in general. The purpose of the *Ice Engineering Information Exchange Bulletin* is information exchange and not the promulgation of Corps policy; thus, guidance on recommended practice in any given area should be sought through appropriate channels or in other documents. This bulletin's contents are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.

The Cold Regions Research and Engineering Laboratory (CRREL) is part of the U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC).

Communications are welcomed. Write to CRREL, ATTN: Tim Pangburn, 72 Lyme Road, Hanover, NH 03755-1290 (e-mail Timothy.Pangburn@erdc.usace.army.mil), or call 603-646-4296.